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Stress Reduction in sputtered thin NiFe 81/19 layers for Magnetic Field Sensors

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Abstract

Flexible magnetic field sensors using the anisotropic magnetoresistive effect that have been developed within the Collaborative Research Center 653 are to be transferred into industrial applications. Occurring challenges result from interactions between the flexible polyimide substrate and the functional layer namely a thin NiFe 81/19 film deposited by a DC sputter process. We have optimized the DC sputter process with regard to stress and roughness reduction.

Keywords: Flexible Substrate; Collaborative Research Center 653, stress in metallic thin films

1. Introduction

The field of flexible electronics is a growing market due to their small installation space, low costs and low weight. Magnetoresistance (MR) is a frequently used sensing technology, especially the Anisotropic Magnetoresistive (AMR) sensor due to its simple structure. The combination of AMR sensing technology and flexible electronics can lead to a new generation of sensing devices with many advantages: New installation spaces will be accessible for example small air gaps in electro motors or uneven and rough surfaces.

Additional, decreasing prices per unit of the sensors make the integration of a plurality of sensors affordable for the

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user, which leads to a higher data- and information density. This is especially of interest for machine tools in modern production technology, which have an increasing demand towards precision and efficiency. The Collaborative Research Centre 653 that is funded by the German Research Foundation (DFG) seizes this topic. The approach is to enhance products and processes by collecting information during the product's load during its whole lifetime and storing the same within the observed component in order to enhance the next product generation [1].
Already several electronic compounds as for example feed lines are realized on flexible substrates for the afore mentioned benefits but not the whole device itself. The reason lies within the interaction between the flexible substrate (usually a polymer) and the functional layer of the sensor – a thin metal layer of NiFe 81/19 in the range of nm. In a different way from rigid substrates, the NiFe 81/19 layer develops microstructural defects during its growth, which in turn results in influences on the magnetic properties. We investigate sputtered NiFe 81/19 thin films on polyimide that have been fabricated with a DC Magnetron Generator. The aim is to optimize the parameters of the deposition in a way that the intrinsic tensions and the surface roughness become minimized.

2. Stress and roughness in sputter deposited thin NiFe 81/19 layers on polyimide substrates

When coating a polyimide substrate in a sputter deposition process with a metal layer stress can occur in the metal layer due to several impacts. Thermal stress will appear caused by the differences in the thermal expansion coefficients α. In this investigation the used polyimide features a value for α of 3 ppm/K and NiFe 81/19 has a thermal expansion coefficient α of 13,5 ppm/K leading to tensile stress. Thermal stress rises with a rising deposition temperature under the condition that the later application takes place at room temperature. On the other hand, does a rising deposition temperature reduce intrinsic stresses that can occur from lattice defects, by recovery and recrystallization.

The polyimide itself will transfer a tensile stress into the NiFe 81/19 layer. Here it should be mentioned that previous investigations already showed, that this polyimide has the less intrinsic stress compared with other polyimides and is the most suitable for magnetic devices [2].

Intrinsic tensile or compressive stresses develop from defects inside the microstructural layer, most likely from grain boundaries and lattice defects that reproduce themselves during growth. The magnetic behavior of a sputtered NiFe 81/19 layer is dependent on its microstructure, which again is dependent on the chosen deposition parameters. We varied the parameters temperature, argon flow and generator power. These factors influence the sputter deposition with regard to the amount of target atoms and their energy that are released which defines the probability of collisions as well. Consequently, the direction and the kinetic energy, with which the atoms impinge on the polyimide substrate, is determined by these parameters as well.

3. Sample Preparation

The specimens have been fabricated on a polished 500 µm thick silicon wafer. A polyimide precursor has been spin coated on top of the wafer and was polymerized by heat treatment at 350 °C under nitrogen environment resulting in a 6 µm thick polyimide layer. The wafer is coated with a sputtered 100 nm thick NiFe 81/19 layer and photolithographically structured in an Ion Beam etching process resulting in single sensors with a meandric shape featuring dimensions shown in Fig. 1.
The difference in the various samples lies within the parameters with which the 100 nm thick NiFe 81/19 layer has been deposited. The used parameter range is shown in Table 1. The temperature treatment took place just before the deposition for 30 minutes without a break of vacuum. Different parameter combinations have been carried out in a DoE using an experimental L_9 Matrix according to Taguchi.

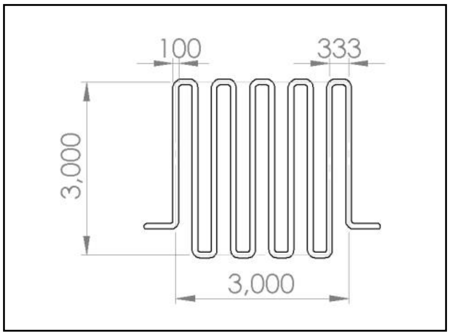


Figure 1: Dimensions of the meander in mm.

Table 1. Experimental L_9 Matrix after Taguchi

Parameter Variation No.	Argon flux [sccm]	Power Generator [W]	Temperature [°C]
1	20	500	RT
2	20	750	150
3	20	1000	300
4	50	500	150
5	50	750	300
6	50	1000	RT
7	80	500	300
8	80	750	RT
9	80	1000	150

4. Experimental Results

4.1. Resistivity

Resistivity δ is the reciprocal value of conductivity. It is measured using a four point probe. Four needles are equally placed in line on top of the metallic surface. A current is injected via the outer two needles. The inner two needles measure the voltage drop. In this way the contact resistance does not falsify the measurement.

In literature, the resistivity of NiFe 81/19 is appointed at 0.55 $x10^{-6}$ Ωm for bulk material at room temperature (RT) [3]. However, resistivity is dependent not only on temperature but also on layer thickness [4]. As the samples all feature the same thickness and are measured at room temperature, the differences in resistivity most likely result only from the differences in the lattice structure.

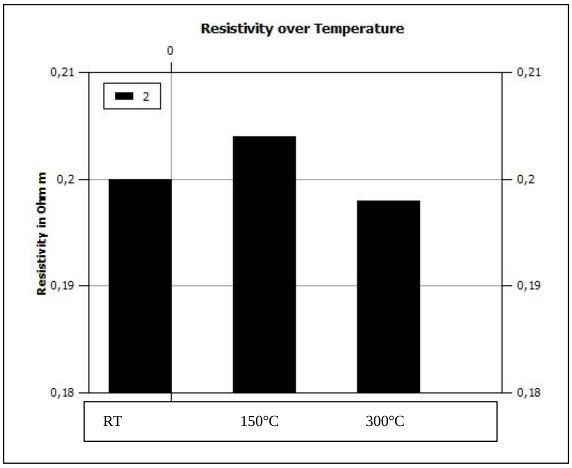
The lowest resistivity of 0.191 $x10^{-6}$ and 0.192 $x10^{-6}$ Ωm could be measured for the parameter variations No. 3 and 5. In these parameter variations, the samples were heated before deposition to 300 °C for 30 minutes. The argon flux is relatively low 20 or 50 sccm and the generator's power lies in the upper range of 1000 or 750 W. The decrease of resistivity indicates a reduction of lattice defects in the metallic layer. Deposition at elevated temperature leads to a defect poor metallic layer caused by vacancy, interstitial and dislocation movement [5]. At a temperature of 300 °C, even recrystallization is likely to take place in a NiFe 81/19 layer. The third sample, which has been preheated at 300 °C (No.7) shows a degradation of δ compared to the other two samples reaching a value of 0.21 $x10^{-6}$ Ωm. This sample variation combines the high temperature with a high flux density and a low Generator power. It leads to the conclusion that the positive effects on defect annealing by temperature are compensated by the other parameters.

Table 2. Different resistivities resulting from different parameter variations during deposition measures on 18 samples.

Parameter Variation No.	Resistivity [x10^{-6} Ωm]
1	0.202
2	0.202
3	0.192
4	0.206
5	0.192
6	0.194
7	0.210
8	0.204
9	0.203

This correlation becomes clearer by studying the dependence of the resistivity on the argon flux and the generator power. Using a small flux of argon ions of 20 or 50 sccm leads to a relatively resistivity of 0.199 and 0.197 x10^{-6} Ωm respectively on average. A further increase of the argon flux to 80 sccm worsens the value of resistivity to an average of 0.206 x10^{-6} Ωm. It can be concluded that a higher amount of argon ions causes an increased amount of collisions between the target atoms, which impinge on the substrate's surface at various angles consequently. This effect probably leads to more defects in the crystal structure inside of the growing layer.

With a rising power of the generator a decline of resistivity can be observed. A highest value of 0.206x10^{-6} Ωm at 500 W over 0.199 x10^{-6} Ωm at 750 W to 0.196 x10^{-6} Ωm at 1000 W. The higher energy as well causes a more directional impinge of the target atom onside the substrate leading to less defects within the layer. The correlations are depicted in figure 2.



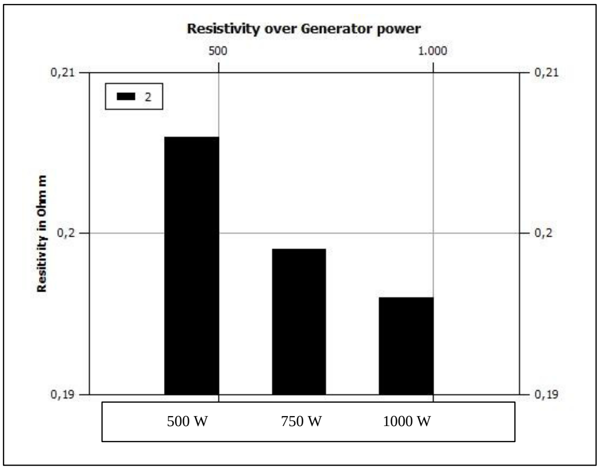
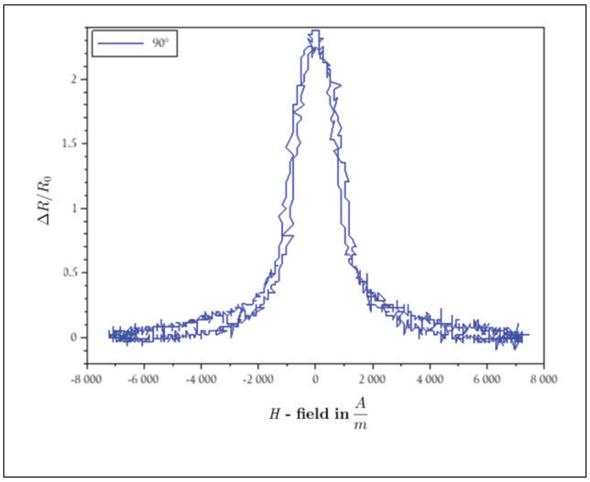


Figure 2 (a) Average resistivity over Temperature (b) Average resistivity over Generator power

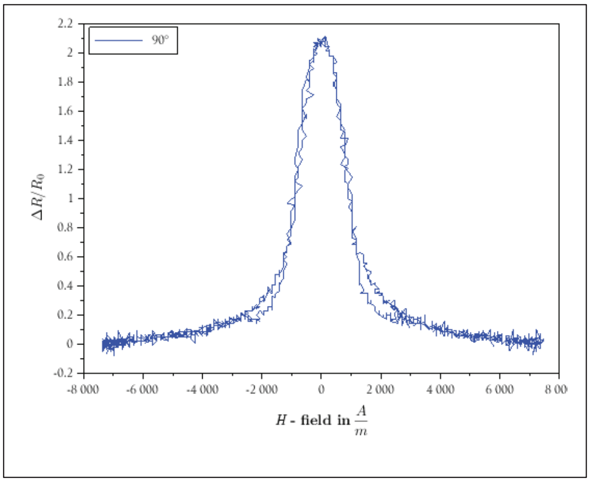
4.2. Magnetization Curve

For the characterization of the magnetic behavior of the NiFe 81/19 samples, the meandric shaped probes were mounted on a fixture, which was located in a Helmholtz coil. The Helmholtz coil generates a homogenous alternating magnetic field. The samples were connected in a Wheatsone Bridge and the output voltage gets amplified by an amplifier that has been developed at the institute. The change of resistance is recorded as a function of the applied field. The resulting R-H hysteresis loop delivers two interesting values being the maximum AMR effect and the shift of the $\Delta R/R_0$ ratio peaks relative to the field.

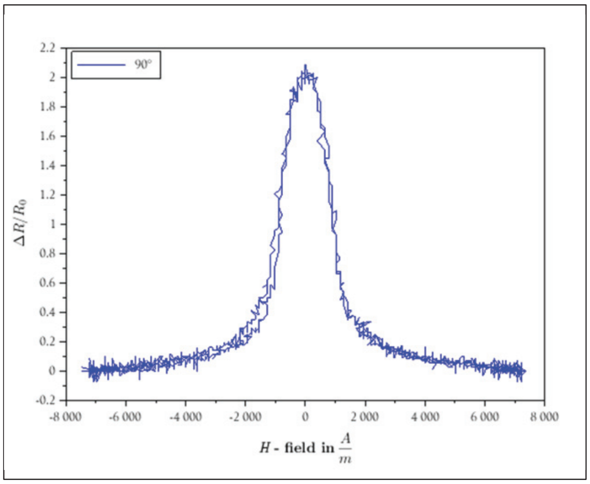
The hysteresis loops of the samples deposited at the parameter variations with the most significant results are depicted in figure 3. The highest value of the AMR effect could be measured with the parameter variation No.2 with an argon flux of 20 sccm, a generator power of 750 W and a preheat treatment at 150 °C reaching a value of 2.37 %. Unfortunately did this sample still exhibit a peak shift of 244 A/m. The lowest peak shift could be achieved with the parameter variation No. 6 with an argon flux of 50 sccm, a generator power of 1000 W and without a preheat treatment reaching a value of 164 A/m but only an AMR effect of 2.01 %. A compromise could be found by parameter variation No. 3 with an argon flux of 20 sccm, a generator power of 1000 W and a preheat treatment at 300 °C reaching a value of 2.12 % AMR effect and a peak shift of 186 A/m.



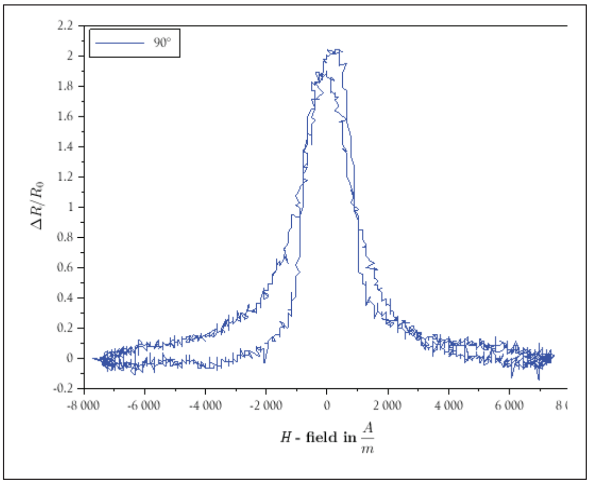
(a)



(b)



(c)



(d)

Figure 3 Hysteresis loop of parameter variation (a) No. 2, (b) No. 6 (c) No. 3 and (d) No. 7.

The DoE shows only a small effect of the argon flux on the AMR effect but a slight enhancement with a decreasing flux density. This approves the theory that a declining argon flux leads to a defect less NiFe 81/19 layer. Also the generator power only provides a marginal change of the AMR effect within the chosen range of value. A significant influence on the change of the AMR effect results from the temperature. The AMR effect reaches its peak at a temperature treatment at 150 °C. When no temperature treatment takes place, no defect annealing is performed. However if the temperature is elevated at 300 °C the AMR declines probably due to the increasing thermal stress which superposes the positive effects of defect annealing. Similar results could be found with regard to the minimum peak shift.

4.3. Roughness

The surface of the NiFe 81/19 layers have been measured with an Atomic Force Microscope (AFM) scanning a square of 5 µm x 5 µm. The measurement is depicted in figure 4. The values for R_a and R_z are summarized in table 3. Not all parameter variations are discussed here. Only four samples are being discussed being the one with the highest AMR effect, the one with the lowest peak shift, a compromise between the two mentioned and the one with a non-satisfying result.

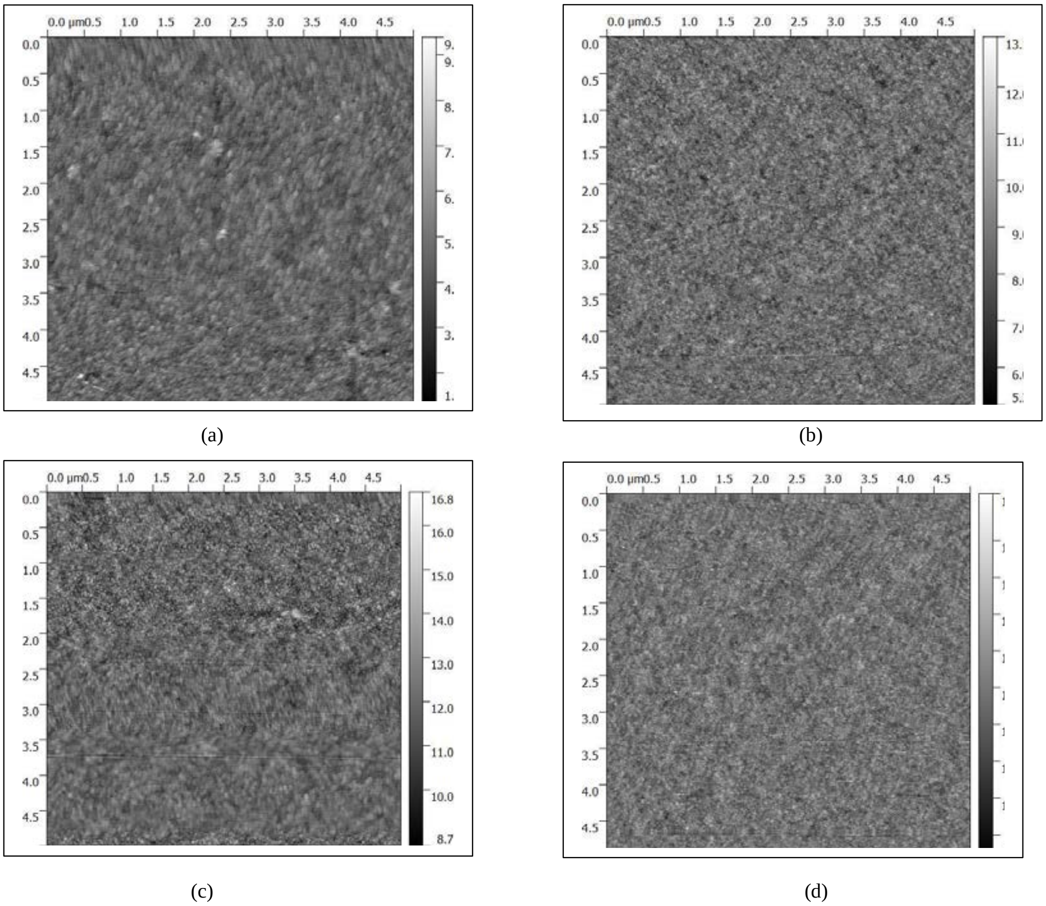


Figure 4 (a) Parameter: argon flux 20 sccm, Power 750 W, Temperature 150°C with the highest value of AMR effect. (b) Parameter: argon flux 50 sccm, Power 1000 W, Temperature 150°C with the highest value of AMR effect. lowest peak shift

Table 3 roughness of different samples

Argon [sccm] | Power [W]| Temperature [°C]	R_a in nm	R_z in nm

20|750|150| highest AMR effect	0.384	5.193
50|1000|RT lowest peak shift	0.551	7.874
20|1000|300 compromise	0.536	8.041
80|500|RT bad combination	0.404	6.199

Figure 4a and 4c show nanocrystalline structures the other two an amorphous surface. All samples have a very low R_a, which suggest the very high quality of the manufactured NiFe 81/19 layers. In this parameter range the influence of the roughness on the AMR effect is expected to be very low [7].

5. Summary and Discussion

The choice of parameter in a sputter deposition process influences the microstructure of the deposited layer and therefore the intrinsic stress as well in addition to the roughness. We could show that an AMR effect of 2.37 %, which is comparable to commercially available AMR sensors on rigid substrates, can be achieved. The low resistivities, the low roughness and the small peak shift emphasize the high quality of the NiFe 81/19 layer. It could be found that the argon flux and the generator power only have a minor effect on the performance of the magnetic sensor, where argon has a higher effect on the AMR effect and the generator power influences more the peak shift. The optimum temperature treatment was examined to be 150 °C.

References

[1] Lachmayer R, Mozgova I, Sauthoff B, Gottwald P. Product evolution and optimization based on gentelligent components and product life cycle data. Smart product engineering lecture notes in production engineering; 2013; pp 685-694

[2] Rittinger J, Taptimthong P, Jogschies L, Wurz M.C, Rissing L. Impact of different polyimide-based substrates on the soft magnetic properties of NiFe thin films, SPIE Microtechnologies, 2015

[3] https://de.wikipedia.org/wiki/Mu-Metall

[4] Mayadas A.F, janak J.F, Gangulee A. Resistivity of Permalloy films, IBM, Thomas J. Watson Research Center, 1974

[5] Thornton J.A, Hoffmann D.W. Stress-related Effects in thin films, thin solid films, 171, 5, 1989

[6] Rittinger J, Taptimthong P, Jogschies L, Wurz M.C, Rissing, L. Magnetic microstructure analysis of sputter deposited permalloy thin films on a spin‐on polyimide substrate, Microsystem Tehcnology, 2015

[7] Choe G, Steinback M. Surface roughness effects on magnetoresistive and magnetic properties of NiFe thin films, Journal of Applied Physics, 85,5777,1999